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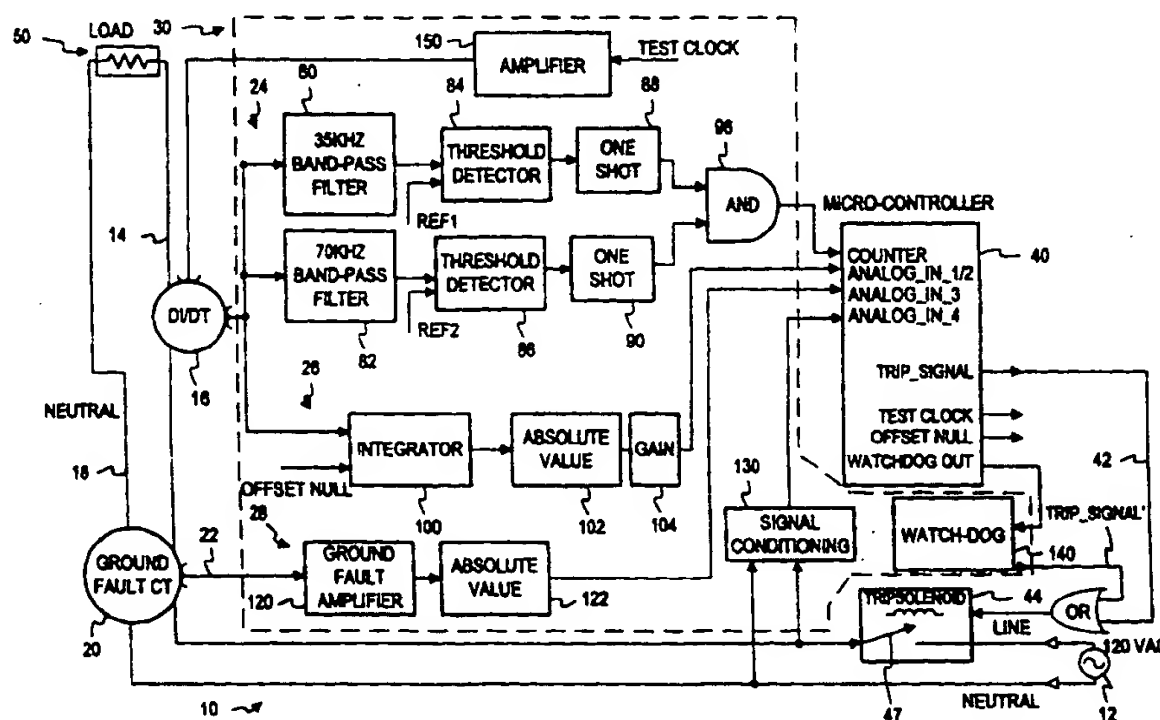
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(54) Title: ELECTRICAL FAULT DETECTION SYSTEM



(57) Abstract

An electrical fault detector system (10) detects (16) electrical faults in an electrical distribution system by monitoring one or more conductors (14, 18) and producing an input signal representing one or more electrical signal conditions in the circuit to be monitored. This input signal is processed to develop a first signal representing the electrical current flow through the monitored circuit and a second signal representing signal components in a selected frequency range typical of arcing faults, and which exceed a predetermined threshold. The system also detects (20) ground faults in the circuit being monitored.

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ELECTRICAL FAULT DETECTION SYSTEM

FIELD OF THE INVENTION

The present invention relates to the protection of electrical circuits and, more particularly, to the detection of various electrical faults in an electrical circuit, for example an analysis of current flow in the circuit, detection of arcing faults and detection
5 of ground faults.

BACKGROUND OF THE INVENTION

The electrical systems in residential, commercial and industrial applications usually include a panelboard for receiving electrical power from a utility source. The power is then routed through protection devices to designated branch circuits supplying
10 one or more loads. These overcurrent devices are typically circuit interrupters such as circuit breakers and fuses which are designed to interrupt the electrical current if the limits of the conductors supplying the loads are surpassed. Interruption of the circuit reduces the risk of injury or the potential of property damage from a resulting fire.

Circuit breakers are a preferred type of circuit interrupter because a resetting
15 mechanism allows their reuse. Typically, circuit breakers interrupt an electric circuit due to a disconnect or trip condition such as a current overload or ground fault. The current overload condition results when a current exceeds the continuous rating of the breaker for a time interval determined by the trip current. A ground fault trip condition is created by an imbalance of currents flowing between a line conductor and a neutral conductor
20 which could be caused by a leakage current or an arcing fault to ground.

Arcing faults are commonly defined as current through ionized gas between two ends of a broken conductor or at a faulty contact or connector, between two conductors supplying a load, or between a conductor and ground. However, arcing faults may not cause a conventional circuit breaker to trip. Arcing fault current levels may be reduced
25 by branch or load impedance to a level below the trip curve settings of the circuit breaker. In addition, an arcing fault which does not contact a grounded conductor or person will not trip a ground fault protector.

There are many conditions that may cause an arcing fault. For example, corroded, worn or aged wiring, connectors, contacts or insulation, loose connections,

wiring damaged by nails or staples through the insulation, and electrical stress caused by repeated overloading, lightning strikes, etc. These faults may damage the conductor insulation and reach an unacceptable temperature. Arcing faults can cause fire if combustible materials are in close proximity.

5 OBJECTS AND SUMMARY OF THE INVENTION

It is an object of the present invention to provide an electrical fault detection system and method which reliably detects electrical faults, including overcurrent conditions and ground faults, as well as arc fault conditions ignored by conventional circuit interrupters.

10 Still another object of the invention is to provide an electrical fault detection system which utilizes a minimum number of highly reliable electronic components to perform most of the signal processing and analyzing functions, so as to be relatively simple and yet highly reliable in operation.

Other and further objects and advantages of the invention will be apparent to
15 those skilled in the art from the present specification taken with the accompanying drawings and appended claims.

In accordance with one aspect of the invention, there is provided an electrical circuit fault detector comprising band-pass filter circuit means responsive to an input signal representative of an electrical signal condition in a circuit to be monitored for
20 passing a frequency signal comprising signal components of said input signal which fall within a first predetermined frequency band; threshold detector circuit means coupled to said band-pass filters circuit means and responsive to components of said frequency signal above a predetermined threshold amplitude for producing a corresponding frequency amplitude signal; and first frequency signal conditioning circuit means
25 coupled to said threshold detector means and responsive to said frequency amplitude signal for producing a conditioned frequency amplitude output signal in a form suitable for input to a controller.

In accordance with another aspect of the invention, there is provided an electrical fault detector system comprising a first sensor operatively coupled with a circuit to be
30 monitored for producing an input signal representative of a signal condition in said circuit to be monitored; a ground fault sensor operatively coupled with said circuit to be

monitored for producing a ground fault input signal representative of a ground fault current in said circuit to be monitored; integrator circuit means coupled with said first sensor and responsive to said input signal for developing a current signal representative of current magnitude in said circuit to be monitored; band-pass filter circuit means
5 operatively coupled with said first sensor and responsive to said input signal for passing a frequency signal comprising signal components of said input signal in a predetermined frequency band; ground fault amplifier circuit means coupled with said ground fault sensor for amplifying said input signals to produce amplified ground fault signals; and signal conditioning circuit means coupled with said band-pass filter circuit means, said
10 integrator circuit means and said ground fault amplifier circuit means for receiving and conditioning said current signal, said frequency signal and said amplified ground fault signal to produce conditioned output signals in a form suitable for input to a controller.

In accordance with another aspect of the invention, there is provided a method of detecting arcing faults in an electrical distribution system that includes a line conductor
15 connected to a load, said method comprising monitoring the line conductor and producing a corresponding input signal; and band-pass filtering said input signal at two predetermined frequency bands.

In accordance with another aspect of the invention, there is provided an application specific integrated circuit comprising band-pass filter circuit means
20 responsive to an input signal representative of a signal condition in a circuit to be monitored for passing a frequency signal comprising signal components of said input signal which fall within a first predetermined frequency band; threshold detector circuit means coupled to said band-pass filter circuit means and responsive to components of said frequency signal above a predetermined threshold amplitude for producing a
25 corresponding frequency amplitude signal; and first frequency signal conditioning circuit means coupled to said threshold detector circuit means and responsive to said frequency amplitude signal for producing a conditioned frequency amplitude output signal in a form suitable for input to a controller.

In accordance with another aspect of the invention, there is provided an electrical
30 fault detector circuit comprising current fault detector circuit means for developing a current signal representative of current magnitude in said circuit to be monitored; arcing

fault detector circuit means for developing an arcing fault signal in response to detection of an arcing fault in said circuit to be monitored; and ground fault detector circuit means for producing a ground fault signal in response to detection of a ground fault in the circuit to be monitored.

5 In accordance with another aspect of the invention, there is provided an application specific integrated circuit for an electrical fault detector system comprising current fault detector circuit means for developing a current signal representative of current magnitude in said circuit to be monitored; arcing fault detector circuit means for developing an arcing fault signal in response to detection of an arcing fault signal in said
10 circuit to be monitored; and ground fault detector circuit means for producing a ground fault signal in response to detection of a ground fault in the circuit to be monitored.

In accordance with another aspect of the invention, there is provided a power supply circuit comprising a voltage regulator circuit for producing a regulated DC voltage; and a zener diode in series with a ground circuit of said voltage regulator circuit
15 for producing positive and negative regulated DC output voltages.

In accordance with another aspect of the invention, there is provided a power supply circuit comprising a rectifier circuit; a series capacitor between a source of line voltage and said rectifier circuit for efficiently dropping said line voltage; and a voltage regulator operatively coupled with said bridge circuit for producing a regulated DC
20 voltage.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a functional block diagram of an electrical fault detection system embodying the invention;

25 FIG. 2 is a schematic diagram of an electrical circuit for implementing the arc fault detection system illustrated in FIG. 1;

FIGS. 3-6 are schematic diagrams of further details of the electrical circuit of FIG. 2; and

FIGS. 7A and 7B and 8A, 8B, 8C and 8D form a schematic diagram of an
30 application specific integrated circuit (ASIC) which functions equivalently to the circuits of FIGS. 3-6.

DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

Referring now to the drawings in initially to FIG. 1, there is shown in block form a novel electrical fault detector system in accordance with the invention, and designated generally by the reference numeral 10. In the illustrative example, the fault detection system 10 is associated with an electrical circuit such as a 120 VAC circuit 12 which is to be monitored for faults. Of course, the invention is not limited to use with a 120 VAC circuit. At least one sensor 16 is provided in association with the 120 VAC circuit 12 for producing a signal representative of a signal condition, such as power, voltage or current in the 120 VAC circuit 12. In the illustrated embodiment, this sensor 16 comprises a current rate of change sensor (di/dt). A line conductor 14 of the 120 VAC circuit 12 passes through the rate of change current sensor (di/dt) 16 which produces a current input signal representative of the rate of change of current flow in the line conductor 14. In the illustrative embodiment, both the line conductor 14 and a neutral circuit 18 of the 120 VAC circuit 12 flow through a ground fault detector or sensor 20 which is responsive to the current flowing through the line and neutral sides of the circuit 12 for producing an output signal at an output 22. If the current flow through the line and neutral conductors is different, this is indicative of a ground fault.

Preferably, the di/dt sensor 16 and the ground fault sensor 20 each comprise a toroidal coil having an annular core which surrounds the relevant conductors, with a toroidal sensing coil wound helically on the core. In the sensor 16, the core may be made of magnetic material such as ferrite, iron or molded permeable powder, such that the sensor is capable of responding to rapid changes in flux. An air gap may be cut into the core in certain instances to reduce the permeability, and the core material is such that it does not saturate during the relatively high current produced by some forms of arcing, so that arc detection is still possible. The particular requirements for the construction of the toroidal coil and core for the ground fault sensor 20 may differ somewhat for those for the di/dt sensor 16, such ground fault sensors or transformers being generally known in the art.

The di/dt sensor 16 provides an input to an arcing fault detector circuit 24 which is preferably a broadband noise detector circuit and a current fault detector circuit 26

which is preferably a current measuring circuit. The ground fault sensor 20 provides an input signal at line 22 to a ground fault detector circuit 28. Preferably, all of the components of the arcing fault circuit detector 24, the current fault detector circuit 26 and the ground fault detector circuit 28, as well as some other circuit components to be described later, are provided on an application specific integrated circuit (ASIC) 30. Suitable output signals from the ASIC 30 are fed to a microcontroller 40 which, based on analysis and further processing of the signals provided by the ASIC 30 makes a decision as to whether to send a trip signal to an output 42 for activating a trip circuit 44 which will in effect switch the line side conductor 14 of the 120 VAC circuit 12 to an open circuit condition as indicated diagrammatically in FIG. 1, or whether to allow the line side 14 of the circuit 12 to remain connected to a load 50.

Referring also to FIG. 2, some additional details of the circuit of the invention are illustrated. In the embodiment illustrated in FIG. 2, the trip signal from the microcontroller output 42 is fed to the ASIC 30 where it is ORed with other signals (to be described later) for tripping the trip circuit 44, and fed to a trip output 32. The illustrated trip circuit 44 includes a trip coil 46, such as a solenoid coil which, when enough current is flowing through it, will activate a solenoid plunger causing it to release a mechanism within a circuit breaker thereby opening the contacts 47 and disconnecting the line from the load 50 as illustrated in FIG. 1. The trip circuit 44 as illustrated in FIG. 2 includes a triac 48 in series with the trip coil 46 and the neutral line 18. This triac 48 will be gated by a photo-sensitive triac 50, when the triac 50 is activated by the emission of light energy from a light emitting diode (LED) 52. The LED 52 is coupled to the "trip out" line 32 of the ASIC and to a negative reference voltage VSS so as to be energized for emitting light when a trip signal is given on the line 32.

Referring briefly to a power supply portion 60 in the circuit of FIG. 2, in the illustrative embodiment a full wave rectifier bridge circuit 62 is employed. Advantageously, a series capacitor 64 is coupled between the line conductor 14 and the rectifier bridge circuit 62 for efficiently dropping the line voltage. In the illustrative embodiment the capacitor has a value of substantially 0.56 microfarads so as to deliver approximately 15-25 volts AC into the rectifier bridge 62. This reduced line voltage is fully rectified and clamped to 14 volts by a 14 volt zener diode 65.

In accordance with another feature of the invention, the cathode of a zener diode 66 is coupled to the ground pin or ground circuit 68 of a voltage regulator 70. The voltage regulator 70 produces a +5 volt DC regulated voltage as VDD, while a similar -5 volt regulated voltage VSS is produced at the anode of the zener diode 66, which is preferably a 5.6 volt zener diode.

Also shown in FIG. 2 is a test switch input 72 to the microcontroller 40 for use in a "push to test" operation. That is, for purposes of testing the circuitry, when a test switch (not shown) coupled with this test switch input 72 is actuated, the resistor R1 will cause a simulated ground fault signal to be injected into the ground fault current transformer 20 for purposes of testing for proper operation of the system. Simultaneously, an AC voltage is coupled to a pin on the microcontroller, causing it to start a self test mode. The microcontroller 40 then will send a "test clock" signal to the ASIC 30 which will condition it and send a simulated arcing fault frequency signal to the di/dt coil 16. If all of the circuitry operates properly, the microcontroller should receive back signals indicating both a ground fault and an arcing fault. In accordance with a test program, only when both of these signals are received, the microcontroller will send an appropriate "trip" signal on line 42 to the "trip in" input of the ASIC 30 which will in turn send a trip signal on "trip out" line 32 to the trip circuit 44 to activate the trip coil 46. Preferably, trip coil 46 is part of a circuit breaker which may be manually reset following the test procedure.

It will be noted that FIG. 2 also indicates schematically the di/dt sensor coil 16 and the ground fault sensor coil 20 and related circuit components and their operative connections to the ASIC 30. Also, the operative connections of additional passive components, of line and neutral sides of the 120 VAC circuit, and of suitable regulated DC voltages from the voltage regulator circuit 60 with respect to the ASIC 30 and the microcontroller 40 are illustrated in FIG. 2.

Referring again to FIG. 1, additional components of the ASIC 30 will next be described.

The broadband noise detector 24 comprises first and second band-pass filter circuits 80, 82 which receive the rate of change of current signal from the di/dt sensor 16. In accordance with the invention, the band passes of these circuits 80 and 82 are selected

at frequency bands which are representative of a frequency spectrum typical of arcing faults so as to substantially (statistically) eliminate signals at frequencies which may occur on the line which do not represent, that is are not due to, an arcing fault. In the illustrative embodiment, these band-pass frequencies are selected as typically 35
5 kilohertz and 70 kilohertz respectively. Each of the band-pass filter circuits 80 and 82 feeds a filtered signal, comprising those components of an input signal from the di/dt sensor which fall within their respective band-pass frequency bands, to respective threshold detector circuits 84 and 86.

The threshold detectors 84 and 86 are responsive to those components of the
10 frequency signals passed by the band-pass filters 80 and 82 which are above a predetermined threshold amplitude for producing a corresponding frequency amplitude output to signal conditioning circuits 88 and 90. These circuits 88 and 90 produce a conditioned output signal in a form suitable for input into the microcontroller 40. In the illustrative embodiment, these latter signal conditioning circuits 88 and 90 comprise ten
15 microsecond one-shot circuits for producing a unit pulse signal. The output pulses generated by the one-shots 88 and 90 are squared up at respective wave squarers 90, 92, and 94 (see FIG. 4) before being ANDed at an AND circuit 96 whose output is fed to a "counter" input of the microcontroller 40 as indicated in FIG. 1. In the illustrative embodiment, a one volt threshold is utilized by both of the threshold circuits 84 and 86.
20 Further details of the arcing fault detector circuit 24 are also in FIGS. 3 and 4.

Referring briefly to FIGS. 3 and 4, these schematics have been broken into several parts labeled as 3A, 3B and 4A, 4B to facilitate illustration thereof. In addition to the circuits thus far described, the arcing fault detector or broadband noise detector circuit portion 24 also includes an offset adjust circuit 81 which takes the relatively low
25 level signals from the di/dt sensor 16 and adjusts them to eliminate offsets in the following stages. The offset adjust feeds a ten (10) kilohertz high-pass filter 83 which feeds into respective amplifiers 85 and 87 which in turn feed into the respective 35 kilohertz and 70 kilohertz band-pass filters 80 and 82 described above. The outputs of these band-pass filters feed into absolute value circuits 89 and 91 which also include
30 amplifier stages which feed into the threshold detectors 84 and 86 which are illustrated in FIG. 4. It should be appreciated that these circuits as well as other circuits illustrated in

FIGS. 3-6 which form part of the ASIC 30 are shown in equivalent circuit form. The circuit design of the ASIC 30 is as illustrated in FIGS. 7 and 8. However, the functions and operations of the ASIC are believed better understood by reference to the block diagram of FIG. 1 and the equivalent circuits of FIGS. 3-6. FIGS. 7 and 8 have also been
5 broken into several parts labeled as 7A, 7B and 8A, 8B, 8C and 8D. The small diagram in the upper left portion of FIG. 8A shows how FIGS. 8A, 8B, 8C and 8D should be arranged.

Referring now again to FIG. 1, and also to FIG. 3, the current fault sensor or current measuring portion 26 of the ASIC 30 also receives the output signal of the di/dt
10 sensor 16. An integrator circuit 100 develops a signal representative of current magnitude in response to the output of the di/dt sensor 16. This signal is fed to a further signal conditioning circuit portion 102 which includes an absolute value circuit as shown in FIG. 1 and a gain circuit 104 for producing a conditioned current output signal in a form suitable for input to the controller 40.

15 The absolute value circuit 102 is similar in its configuration and function to the absolute value circuits 89 and 91 described above. Briefly, all of these circuits take signals that are both negative- and positive-going and invert any negative going signals to positive signals while passing through positive-going signals unchanged.

The output of the absolute value circuit 102 is fed into the gain circuit 104 which
20 includes a low current gain stage 106 and a high current gain stage 108. Briefly, the low current gain stage 106 applies a relatively greater amount of gain to relatively low currents so as to increase the resolution of the current signal for relatively low current levels. On the other hand, the high current gain stage 108 applies a relatively lower gain to relatively higher current levels in order to maintain a full range of current signal levels
25 through the circuit. The outputs of the respective low current and high current gain stages are fed to the microcontroller 40.

Referring again to FIG. 1 and also FIG. 6, the ground fault sensor 20 feeds a ground fault amplifier 120 and an absolute value circuit 122 which form the ground fault
30 detector circuit 28. The ground fault amplifier 120 essentially amplifies the low level difference in current flow between the line 14 and neutral 18 as detected by the ground fault sensor 20. The absolute value circuit is similar in its operation and function to the

absolute value circuits described above with reference to FIGS. 3 and 4, in that it essentially turns negative-going signals into positive signals and passes positive-going signals through unchanged.

Referring now to FIG. 4B, the line voltage is also conditioned at a circuit 130 and fed to the microcontroller for further analysis and processing. This circuit 130 includes a line voltage divider 132 which divides the line voltage to a lower level suitable for further processing, a difference amplifier 134 which takes the output of the line voltage divider and level shifts it to circuit ground to be rectified, and an absolute value circuit 136. The voltage from the difference amplifier 134 is fed through the absolute value circuit 136 which has the same configuration and function as described above for the previously described absolute value circuits. The output of absolute value circuit 136 is fed to the microcontroller 40.

Referring again to FIG. 1 and also to FIG. 5, a watchdog circuit 140 takes a pulse input (Pulse_In) from the microcontroller 40 to check to see if the microcontroller is still active. If no pulses are present on this output from the microcontroller then a trip signal (Trip_Signal) is sent to the trip circuit by the watchdog circuit 140 (via line 32 of FIG. 2). A related circuit, a voltage (VDD) monitor 142 sends a reset signal (logic 0) to an input of the microcontroller 40 when VDD voltage falls below 4.0 volts DC so as to prevent microcontroller errors.

Referring to FIG. 3A, a "push to test" amplifier circuit 150 is shown. This test circuit portion is also shown and also designated by reference numeral 150 in FIG. 1. This circuit 150 receives the test clock signal from the microcontroller when the "push to test" switch at input 72 is actuated and conditions it for input to a test winding on the di/dt sensor 16 for purposes of the push to test function as described above.

As indicated above, FIGS. 1-8 illustrate one embodiment of an application specific integrated circuit for performing the above-described operations.

Provision of the detector circuit as an ASIC is advantageous, in that it permits the circuitry to be readily incorporated into a variety of environments. This is mainly due to the small size and relatively modest power requirements of the ASIC. That is, this detector circuit can be incorporated not only in panel boards or other distribution apparatus, but could also be located at individual loads. This is true for industrial, as

well as and commercial and residential applications. For example, the detector circuit ASIC could be incorporated in electrically powered industrial and/or commercial equipment or machinery, as well as in consumer products such as computers, audiovisual equipment, appliances or the like.

5 What has been illustrated and described here is a novel and improved electrical fault detector system including a novel detector circuit and a novel ASIC incorporating the detector circuit. Also described above is a novel and improved power supply circuit.

10 While particular embodiments and applications of the present invention have been illustrated and described, it is to be understood that the invention is not limited to the precise construction and compositions disclosed herein and that various modifications, changes, and variations may be apparent from the foregoing descriptions without departing from the spirit and scope of the invention as defined in the appended claims.

WHAT IS CLAIMED IS:

1. An electrical fault detector comprising:

band-pass filter circuit means responsive to an input signal representative of an electrical signal condition in a circuit to be monitored for passing a frequency signal
5 comprising signal components of said input signal which fall within a first predetermined frequency band;

threshold detector circuit means coupled to said band-pass filter circuit means and responsive to components of said frequency signal above a predetermined threshold amplitude for producing a corresponding frequency amplitude signal; and

10 first frequency signal conditioning circuit means coupled to said threshold detector circuit means and responsive to said frequency amplitude signal for producing a conditioned frequency amplitude output signal in a form suitable for input to a controller.

2. An electrical fault detector according to claim 1 and further including second band-pass filter circuit means responsive to said input signal for passing a
15 frequency signal comprising signal components of said input signal which fall within a second predetermined frequency band;

second threshold detector circuit means coupled to said second band-pass filter means and responsive to components of said frequency signal above a predetermined threshold amplitude for producing a corresponding frequency amplitude signal;

20 second frequency signal conditioning circuit means coupled to said second threshold detector circuit means and responsive to said frequency amplitude signal for producing a second conditioned frequency amplitude output signal in a form suitable for input to a controller; and

AND circuit means for receiving and ANDing said conditioned frequency
25 amplitude signals.

3. An electrical fault detector according to claim 2 wherein said first and second frequency bands are selected to be representative of a frequency spectrum typical of arcing faults.

4. An electrical fault detector according to claim 1 wherein said input signal
30 is a current rate of change signal and further including integrator circuit means

responsive to said input signal for developing a current signal representative of current magnitude; and

current signal conditioning circuit means coupled with said integrator circuit means and responsive to said current signal for producing a conditioned current output
5 signal in a form suitable for input to a controller.

5. An electrical fault detector according to claim 1 and further including ground fault amplifier circuit means for amplifying signals from a ground fault sensor to produce amplified ground fault signals; and

ground fault signal conditioning circuit means coupled to said ground fault
10 amplifier and responsive to said amplified ground fault signals for producing conditioned ground fault signals in a form suitable for input to a controller.

6. An electrical fault detector according to claim 1 wherein said first frequency signal conditioning circuit means comprises one-shot means responsive to said frequency amplitude signal for producing a unit pulse signal comprising said conditioned
15 frequency amplitude signal.

7. An electrical fault detector according to claim 2 wherein said second frequency signal conditioning circuit means comprises second one-shot means responsive to said frequency amplitude signal for producing a unit pulse signal comprising said conditioned frequency amplitude signal.

20 8. An electrical fault detector according to claim 4 wherein said current signal conditioning circuit comprises a low gain circuit for adjusting a gain of said current signal by first predetermined amount and a high gain circuit for adjusting a gain of said current signal by second predetermined amount greater than said first predetermined amount, for increasing resolution of said current signal for relatively low
25 current levels while maintaining a full range of current signal levels for relatively high current levels.

9. An electrical fault detector according to claim 4 and further including a current offset adjust circuit coupled between said integrator circuit means and said current signal conditioning circuit means for amplifying and level shifting said current
30 signal to eliminate offsets.

10. An electrical fault detector according to claim 9 and further including absolute value circuit means coupled between said current offset adjust circuit means and said current signal conditioning circuit means for inverting any negative current signal to a positive current signal and for passing through positive current signals unchanged.

5 11. An electrical fault detector according to claim 1 and further including a current rate of change sensor transformer for producing said input signal.

12. An electrical fault detector according to claim 5 and further including a ground fault sensor transformer comprising said ground fault sensor.

10 13. An electrical fault detector according to claim 1 and further including a controller coupled with said first frequency signal conditioning circuit means for receiving said output signal.

14. An electrical fault detector according to claim 2 and further including a controller coupled with said AND circuit means for receiving the ANDed signals.

15 15. An electrical fault detector according to claim 4 and further including a controller coupled with all of said signal conditioning circuit means for receiving all of said output signals.

16. An electrical fault detector according to claim 5 and further including a controller coupled with all of said signal conditioning circuit means for receiving all of said output signals.

20 17. An electrical fault detector system comprising:
a first sensor operatively coupled with a circuit to be monitored for producing an input signal representative of a signal condition in said circuit to be monitored;

a ground fault sensor operatively coupled with said circuit to be monitored for producing a ground fault input signal representative of any ground fault current in said
25 circuit to be monitored;

band-pass filter circuit means operatively coupled with said first sensor and responsive to said input signal for passing a frequency signal comprising signal components of said input signal in a predetermined frequency band;

ground fault amplifier circuit means coupled with said ground fault sensor for
30 amplifying said input signal to produce amplified ground fault signals; and

signal conditioning circuit means coupled with said band-pass filter circuit means, said integrator circuit means and said ground fault amplifier circuit means for receiving and conditioning said current signal, said frequency signal and said amplified ground fault signal to produce conditioned output signals in a form suitable for input to a controller.

18. A system according to claim 17 and further including a controller operatively coupled with said signal conditioning circuit for receiving said output signals.

19. A system according to claim 17 and further including threshold detector circuit means coupled between said band-pass filter circuit means and said signal conditioning circuit means and for passing substantially only components of said frequency signal above a pre-selected threshold amplitude to said signal conditioning circuit means.

20. A system according to claim 19 and further including second band-pass filter circuit means coupled with said first sensor and responsive to said input signal for passing a frequency signal comprising signal components of said input signal in a second predetermined frequency band and second threshold detector circuit means coupled between said band-pass filter means and said signal conditioning circuit means for passing substantially only those components of the frequency signal above a pre-selected threshold amplitude to said signal conditioning circuit means.

21. A system according to claim 20 wherein said first and second frequency bands are selected to be representative of a frequency spectrum typical of arcing faults so as to substantially eliminate signals at frequencies not representing an arcing fault.

22. A system according to claim 17 wherein said first sensor comprises a current rate of change sensor, and further including integrator circuit means coupled with said rate of current change sensor and responsive to said input signal for developing a current signal representative of current magnitude in said circuit to be monitored; and wherein said signal conditioning circuit comprises a low gain circuit for adjusting a gain of said current signal by a first predetermined amount and a high gain circuit for adjusting a gain of said current signal by a second predetermined amount greater than said first predetermined amount, for increasing resolution of said current signal for

relatively low current levels while maintaining a full range of current signal levels for relatively high current levels.

23. A system according to claim 17 and further including a power supply circuit, said power supply circuit including:

5 a rectifier circuit;

a series capacitor coupled between a source of line voltage and said rectifier circuit for efficiently dropping said line voltage; and

a voltage regulator circuit operatively coupled with said rectifier circuit for producing a regulated direct current voltage.

10 24. A system according to claim 23, wherein said power supply circuit further includes a zener diode in series with a ground circuit of said voltage regulator circuit for producing positive and negative regulated direct current output voltages.

25. A system according to claim 17 and further including a trip circuit responsive to a trip signal for causing an open circuit condition in the circuit to be
15 monitored.

26. A method of detecting arcing faults in an electrical distribution system that includes a line conductor connected to a load, said method comprising:

monitoring the line conductor and producing an input signal corresponding to a signal condition in the line conductor; and

20 band-pass filtering said input signal at two predetermined frequency bands.

27. A method according to claim 26 and further including the steps of detecting components of the band-pass filtered signal above a pre-selected threshold amplitude and producing an output signal representing that portion of the band-pass filtered signal has an amplitude above said pre-selected threshold amplitude; and
25 generating an arc fault detection signal in response to said output signal.

28. An application specific integrated circuit comprising:

band-pass filter circuit means responsive to an input signal representative of a signal condition in a circuit to be monitored for passing a frequency signal comprising signal components of said input signal which fall within a first predetermined frequency
30 band;

threshold detector circuit means coupled to said band-pass filters circuit means and responsive to components of said frequency signal above a predetermined threshold amplitude for producing a corresponding frequency amplitude signal; and

first frequency signal conditioning circuit means coupled to said threshold
5 detector circuit means and responsive to said frequency amplitude signal for producing a conditioned frequency amplitude output signal in a form suitable for input to a controller.

29. An application specific integrated circuit according to claim 28 and further including second band-pass filter circuit means responsive to said input signal for passing a frequency signal comprising signal components of said input signal which fall
10 within a second predetermined frequency band;

second threshold detector circuit means coupled to said second band-pass filter means and responsive to components of said frequency signal above a predetermined threshold amplitude for producing a corresponding frequency amplitude signal;

second frequency signal conditioning circuit means coupled to said second
15 threshold detector circuit means and responsive to said frequency amplitude signal for producing a second conditioned frequency amplitude output signal in a form suitable for input to a controller; and

AND circuit means for receiving and ANDing said conditioned frequency amplitude signals.

20 30. An application specific integrated circuit according to claim 29 wherein said first and second frequency bands are selected to be representative of a frequency spectrum typical of arcing faults.

31. An application specific integrated circuit according to claim 28 wherein said input signal is a current rate of change signal and further including integrator circuit
25 means responsive to said input signal for developing a current signal representative of current magnitude; and

current signal conditioning circuit means coupled with said integrator circuit means and responsive to said current signal for producing a conditioned current output signal in a form suitable for input to a controller.

32. An application specific integrated circuit according to claim 28 and further including ground fault amplifier circuit means for amplifying signals from a ground fault sensor to produce amplified ground fault signals; and

ground fault signal conditioning circuit means coupled to said ground fault
5 amplifier and responsive to said amplified ground fault signals for producing conditioned ground fault signals in a form suitable for input to a controller.

33. An application specific integrated circuit according to claim 28 wherein said first frequency signal conditioning circuit means comprises one-shot means responsive to said frequency amplitude signal for producing a unit pulse signal
10 comprising said conditioned frequency amplitude signal.

34. An application specific integrated circuit according to claim 29 wherein said second frequency signal conditioning circuit means comprises second one-shot means responsive to said frequency amplitude signal for producing a unit pulse signal comprising said conditioned frequency amplitude signal.

15 35. An electrical fault detector circuit comprising:
current fault detector circuit means for developing a current signal representative of current magnitude in said circuit to be monitored;
arcing fault detector circuit means for developing an arcing fault signal in response to detection of an arcing fault in said circuit to be monitored; and
20 ground fault detector circuit means for producing a ground fault signal in response to detection of a ground fault in the circuit to be monitored.

36. An electrical fault detector circuit according to claim 35 wherein said arcing fault detector circuit comprises:

band-pass filter circuit means responsive to an input signal representative of a
25 signal condition in a circuit to be monitored for passing a frequency signal comprising signal components of said input signal which fall within a first predetermined frequency band;

threshold detector circuit means coupled to said band-pass filters circuit means and responsive to components of said frequency signal above a predetermined threshold
30 amplitude for producing a corresponding frequency amplitude signal; and

first frequency signal conditioning circuit means coupled to said threshold detector circuit means and responsive to said frequency amplitude signal for producing a conditioned frequency amplitude output signal in a form suitable for input to a controller.

37. An electrical fault detector circuit according to claim 36 and further including second band-pass filter circuit means responsive to said input signal for passing a frequency signal comprising signal components of said input signal which fall within a second predetermined frequency band;

second threshold detector circuit means coupled to said second band-pass filter means and responsive to components of said frequency signal above a predetermined threshold amplitude for producing a corresponding frequency amplitude signal;

second frequency signal conditioning circuit means coupled to said threshold detector circuit means and responsive to said frequency amplitude signal for producing a conditioned frequency amplitude output signal in a form suitable to a controller; and

AND circuit means for receiving and ANDing said first and second conditioned frequency amplitude signals.

38. An electrical fault detector according to claim 37 wherein said first and second frequency bands are selected to be representative of a frequency spectrum typical of arcing faults.

39. An electrical fault detector according to claim 36 wherein said first input signal comprises a current rate of change signal and wherein said current fault detector circuit means includes integrator circuit means responsive to said input signal for developing a current signal representative of current magnitude, and

current signal conditioning circuit means coupled with said integrator circuit means and responsive to said current signal for producing a conditioned current output signal in a form suitable for input to a controller.

40. An electrical fault detector according to claim 35 wherein said ground fault detector circuit means includes ground fault amplifier circuit means for amplifying signals from a ground fault sensor to produce amplified ground fault signals, and

ground fault signal conditioning circuit means coupled to said ground fault amplifier and responsive to said amplified ground fault signals for producing conditioned ground fault signals in a form suitable for input to a controller.

41. An electrical fault detector according to claim 36 wherein said first frequency signal conditioning circuit means comprises one-shot means responsive to said frequency amplitude signal for producing a unit pulse signal comprising said conditioned frequency amplitude signal, and wherein said second frequency signal conditioning
5 circuit means comprises second one-shot means responsive to said frequency amplitude signal for producing a unit pulse signal comprising said conditioned frequency amplitude signal.

42. An electrical fault detector according to claim 39 wherein said current signal conditioning circuit means comprises a low gain circuit for adjusting a gain of said
10 current signal by first predetermined amount and a high gain circuit for adjusting a gain of said current signal by second predetermined amount greater than said first predetermined amount, for increasing resolution of said current signal for relatively low current levels while maintaining a full range of current signal levels for relatively high current levels.

15 43. An electrical fault detector according to claim 39 and further including a current offset adjust circuit coupled between said integrator circuit means and said current signal conditioning circuit means for amplifying and level shifting said current signal to eliminate offsets; and absolute value circuit means coupled between said current offset adjust circuit means and said current signal conditioning circuit means for
20 inverting any negative current signal to a positive current signal and for passing through positive current signals unchanged.

44. An application specific integrated circuit for an electrical fault detector system comprising:

current fault detector circuit means for developing a current signal representative
25 of current magnitude in said circuit to be monitored;

arcing fault detector circuit means for developing an arcing fault signal in response to detection of an arcing fault in said circuit to be monitored; and

ground fault detector circuit means for producing a ground fault signal in response to detection of a ground fault in the circuit to be monitored.

30 45. An application specific integrated circuit according to claim 44 wherein said arcing fault detector circuit comprises:

band-pass filter circuit means responsive to an input signal representative of a signal condition in a circuit to be monitored for passing a frequency signal comprising signal components of said input signal which fall within a first predetermined frequency band;

5 threshold detector circuit means coupled to said band-pass filters circuit means and responsive to components of said frequency signal above a predetermined threshold amplitude for producing a corresponding frequency amplitude signal; and

first frequency signal conditioning circuit means coupled to said threshold detector circuit means and responsive to said frequency amplitude signal for producing a
10 conditioned frequency amplitude output signal in a form suitable for input to a controller.

46. An application specific integrated circuit according to claim 45 and further including second band-pass filter circuit means responsive to said input signal for passing a frequency signal comprising signal components of said input signal which fall within a second predetermined frequency band;

15 second threshold detector circuit means coupled to said second band-pass filter means and responsive to components of said frequency signal above a predetermined threshold amplitude for producing a corresponding frequency amplitude signal;

second signal conditioning circuit means coupled to said threshold detector circuit means and responsive to said frequency amplitude signal for producing a
20 conditioned frequency amplitude output signal in a form suitable to a controller; and

AND circuit means for receiving and ANDing said first and second conditioned frequency amplitude signals.

47. An application specific integrated circuit according to claim 46 wherein said first and second frequency bands are selected to be representative of a frequency
25 spectrum typical of arcing faults so as to substantially eliminate signals at frequencies not representing an arcing fault.

48. An application specific integrated circuit according to claim 45 wherein said input signal comprises a current rate of change signal and wherein said current fault detector circuit means includes integrator circuit means responsive to said input signal
30 for developing a current signal representative of current magnitude, and

current signal conditioning circuit means coupled with said integrator circuit means and responsive to said current signal for producing a conditioned current output signal in a form suitable for input to a controller.

49. An application specific integrated circuit according to claim 45 wherein
5 said ground fault detector circuit means includes ground fault amplifier circuit means for amplifying signals from a ground fault sensor to produce amplified ground fault signals, and

ground fault signal conditioning circuit means coupled to said ground fault amplifier and responsive to said amplified ground fault signals for producing conditioned
10 ground fault signals in a form suitable for input to a controller.

50. An application specific integrated circuit according to claim 45 wherein said first frequency signal conditioning circuit means comprises one-shot means responsive to said frequency amplitude signal for producing a unit pulse signal comprising said conditioned frequency amplitude signal; and wherein said second
15 frequency signal conditioning circuit means comprises second one-shot means responsive to said frequency amplitude signal for producing a unit pulse signal comprising said conditioned frequency amplitude signal.

51. An application specific integrated circuit according to claim 48 wherein said current signal conditioning circuit means comprises a low gain circuit for adjusting a
20 gain of said current signal by first predetermined amount and a high gain circuit for adjusting a gain of said current signal by second predetermined amount greater than said first predetermined amount. for increasing resolution of said current signal for relatively low current levels while maintaining a full range of current signal levels for relatively high current levels.

25 52. An electrical fault detector circuit according to claim 48 and further including a current offset adjust circuit coupled between said integrator circuit means and said current signal conditioning circuit means for amplifying and level shifting said current signal to eliminate offset; and absolute value circuit means coupled between said current offset adjust circuit means and said current signal conditioning circuit means for
30 inverting any negative current signal to a positive current signal and for passing through positive current signals unchanged.

53. A power supply circuit comprising:

a rectifier circuit;

a series capacitor between a source of line voltage and said rectifier circuit for efficiently dropping said line voltage; and

5 a voltage regulator operatively coupled with said bridge circuit for producing a regulated DC voltage.

54. A power supply circuit according to claim 55 and further including a zener diode in series with a ground circuit of said voltage regulator circuit for producing positive and negative regulated DC output voltages.

10 55. A power supply circuit comprising:

a voltage regulator circuit for producing a regulated DC voltage; and

a zener diode in series with a ground circuit of said voltage regulator circuit for producing positive and negative regulated DC output voltages.

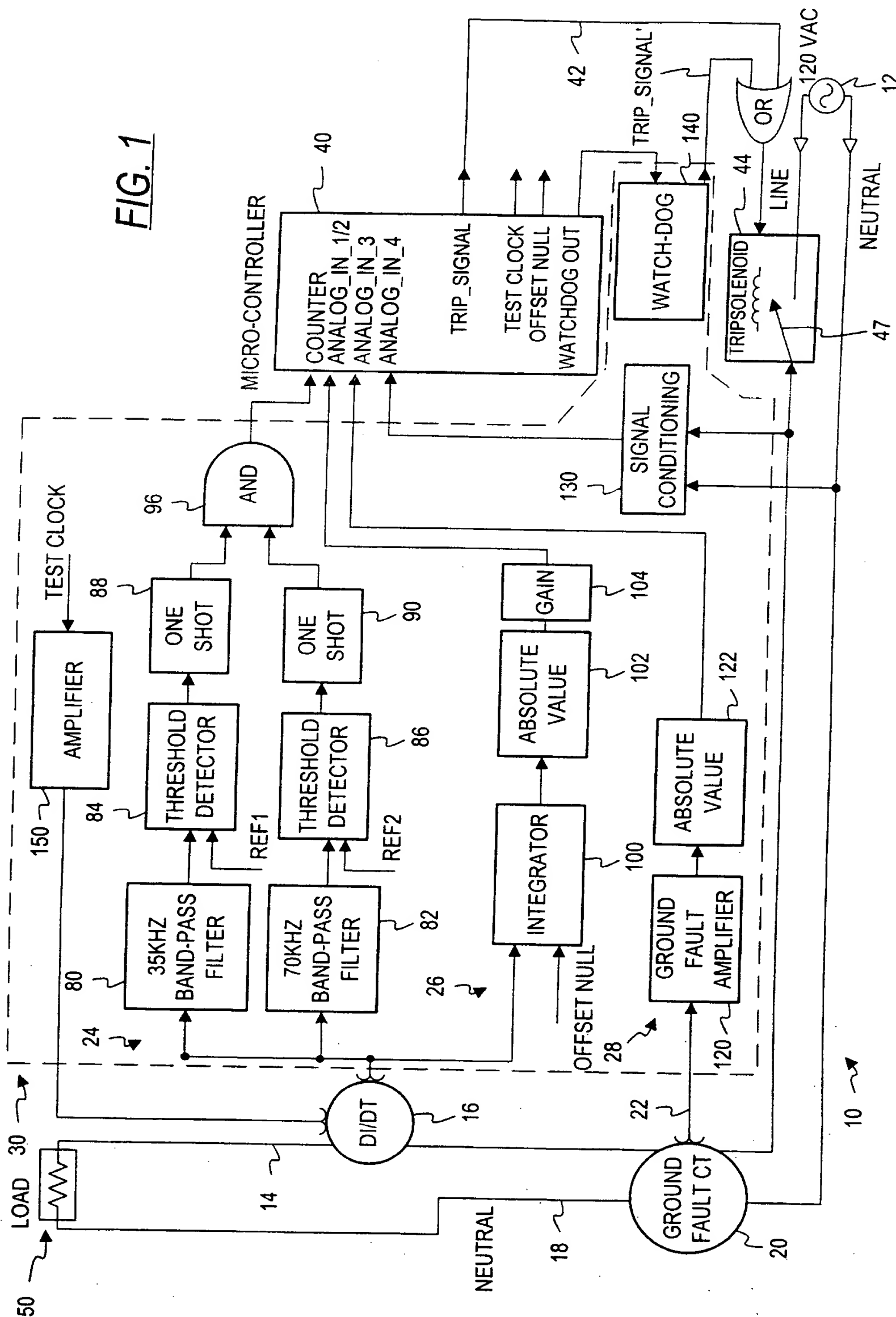
56. An electrical fault detector system according to claim 17 and further
15 including test circuit means for applying a test signal to said first sensor means.

57. An application specific integrated circuit according to claim 44 and further including a test circuit for producing a test input signal for test purposes.

58. An electrical fault detector according to claim 1 and further including a test circuit for producing a test input signal for test purposes.

20 59. An application specific integrated circuit according to claim 28 and further including a test circuit for producing a test input signal for test purposes.

FIG. 1



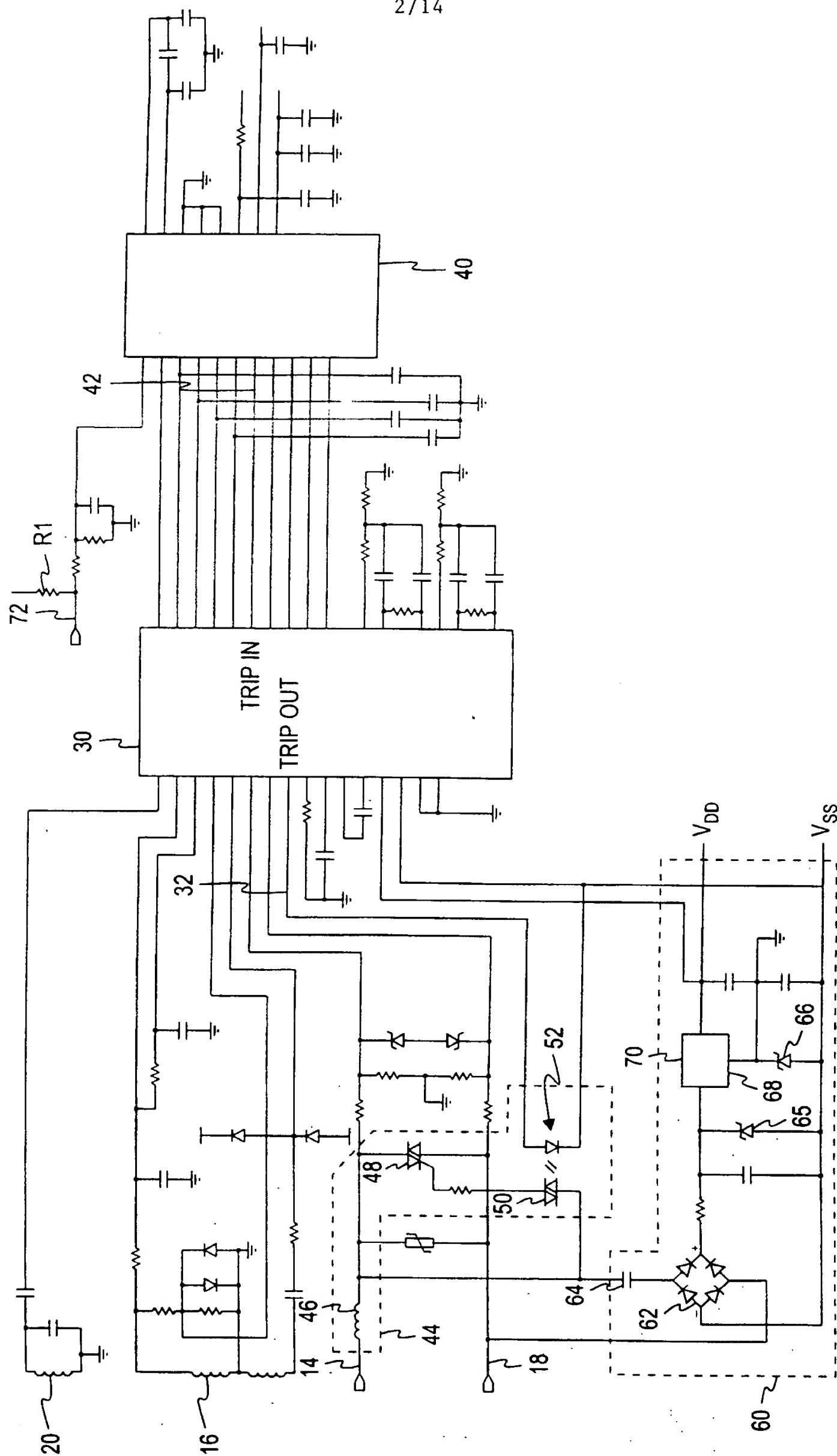
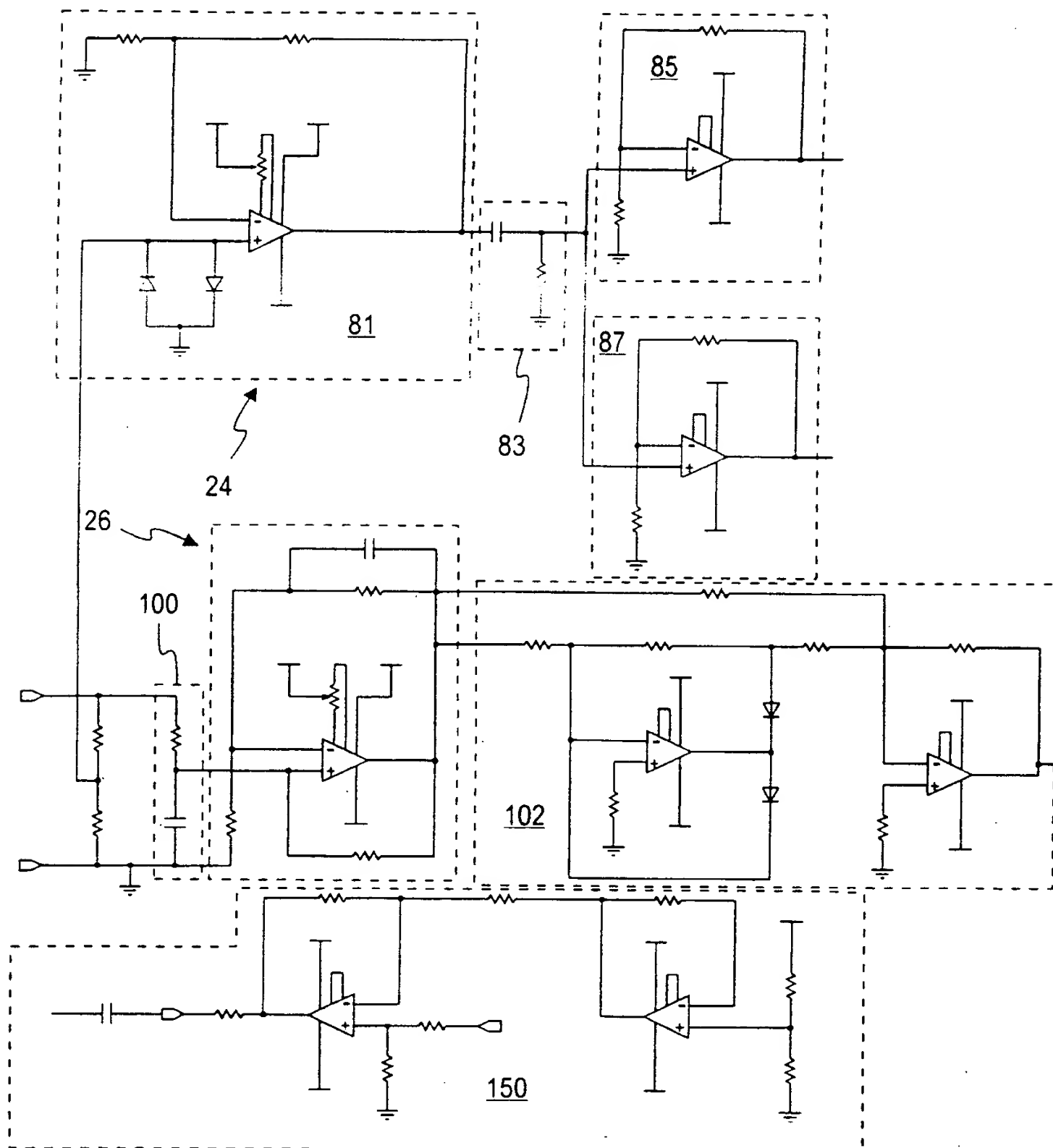
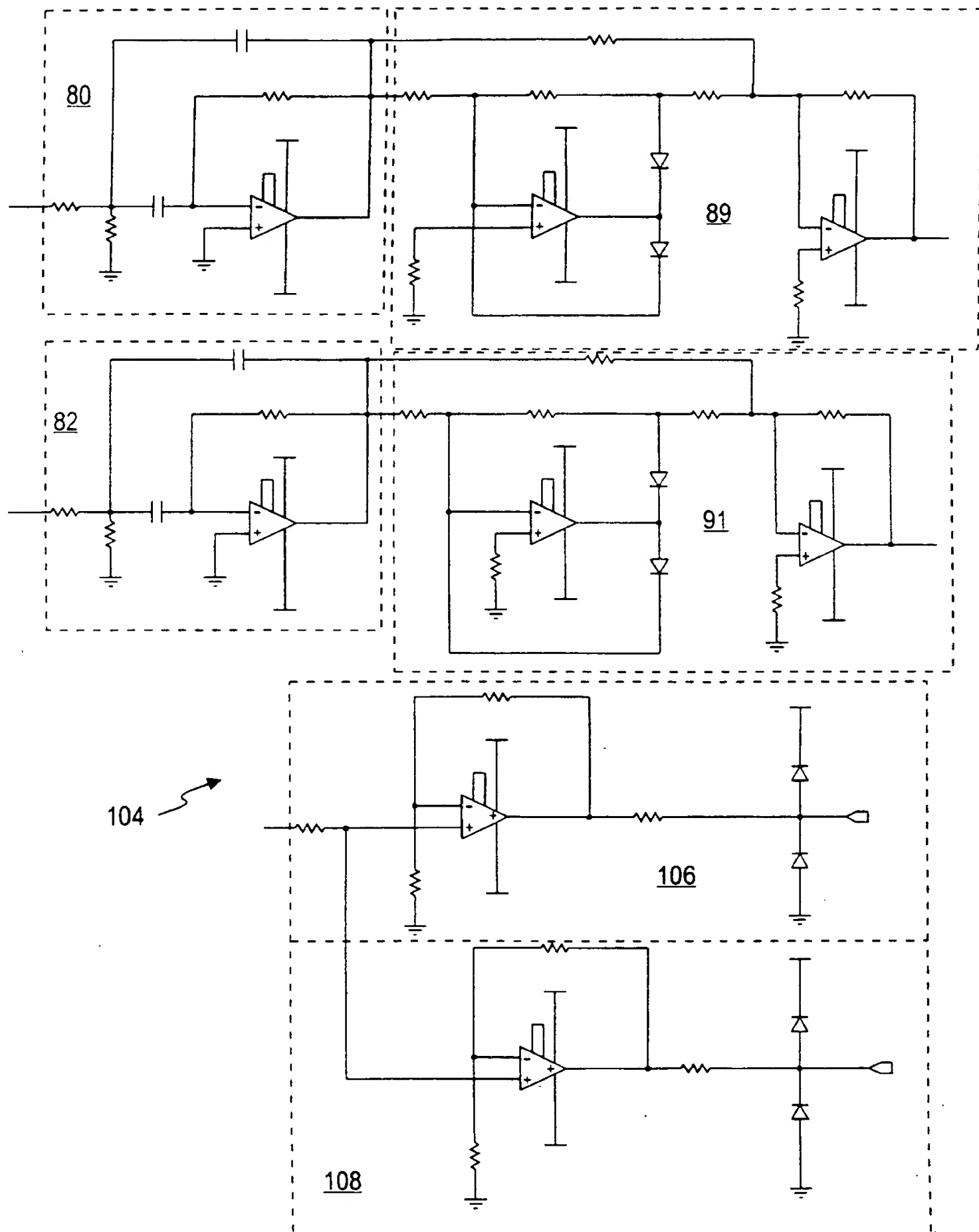


FIG. 2

FIG. 3A

**FIG. 3B**

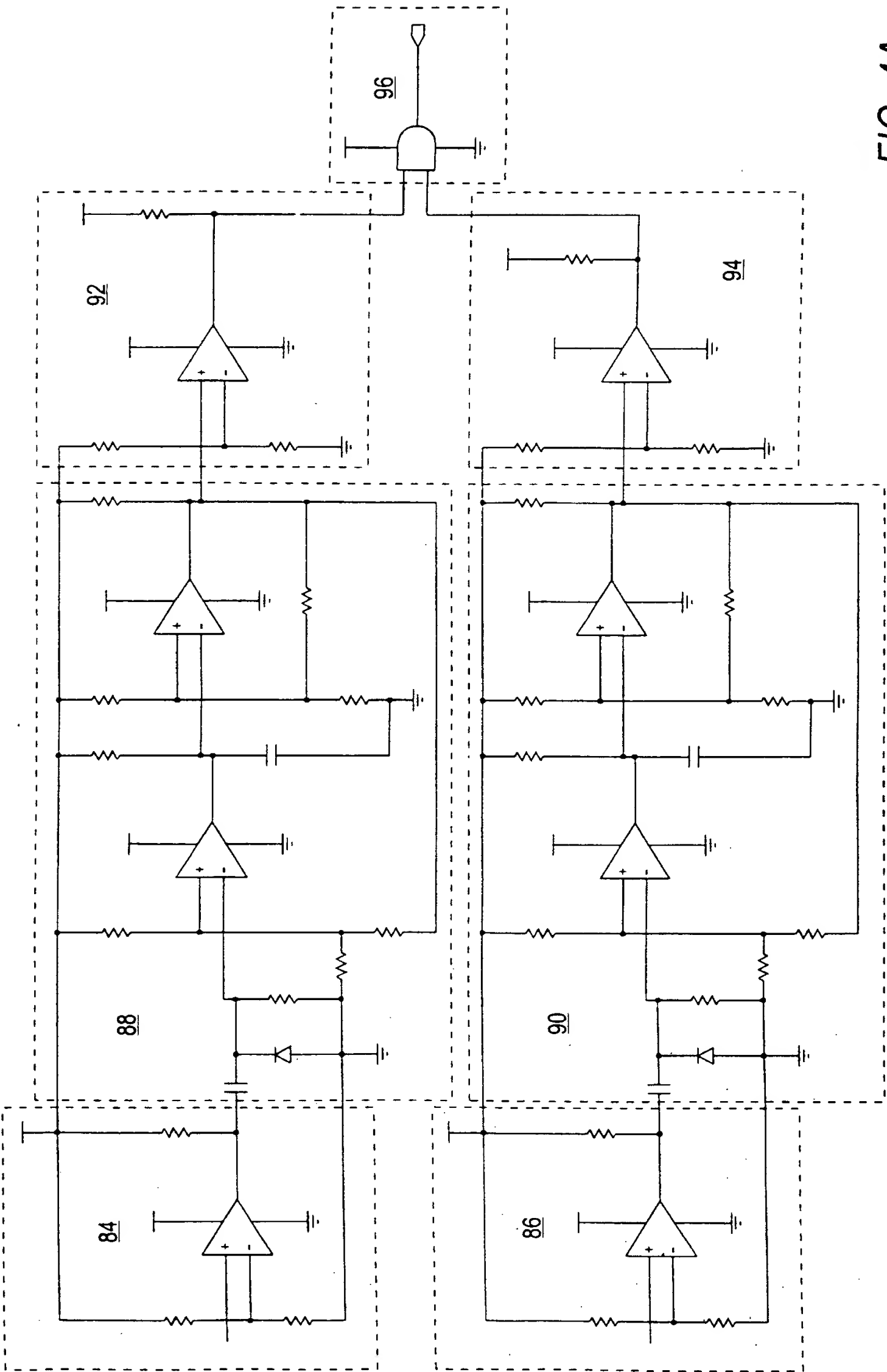


FIG. 4A

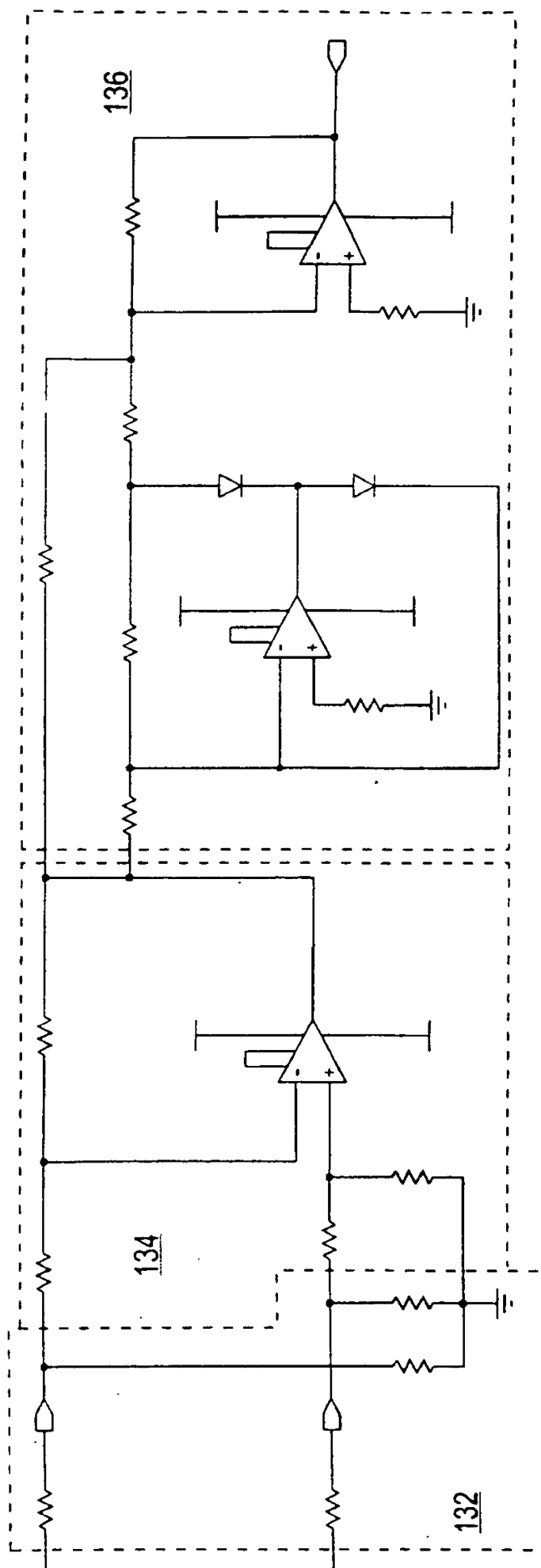


FIG. 4B

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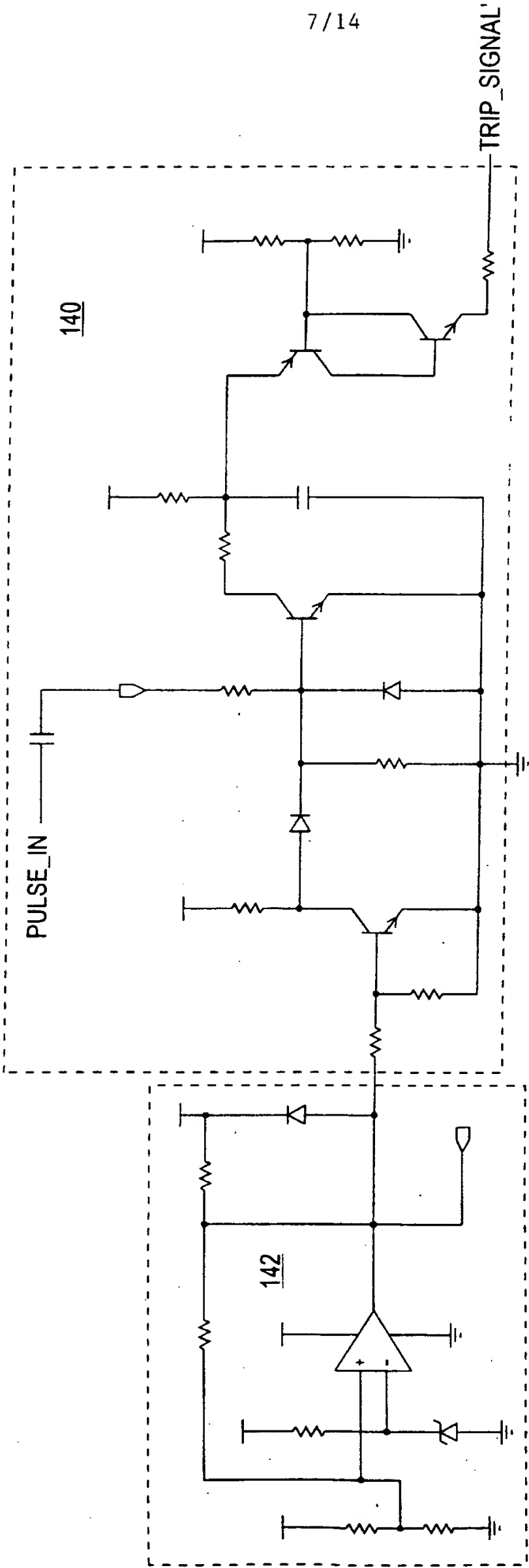


FIG. 5

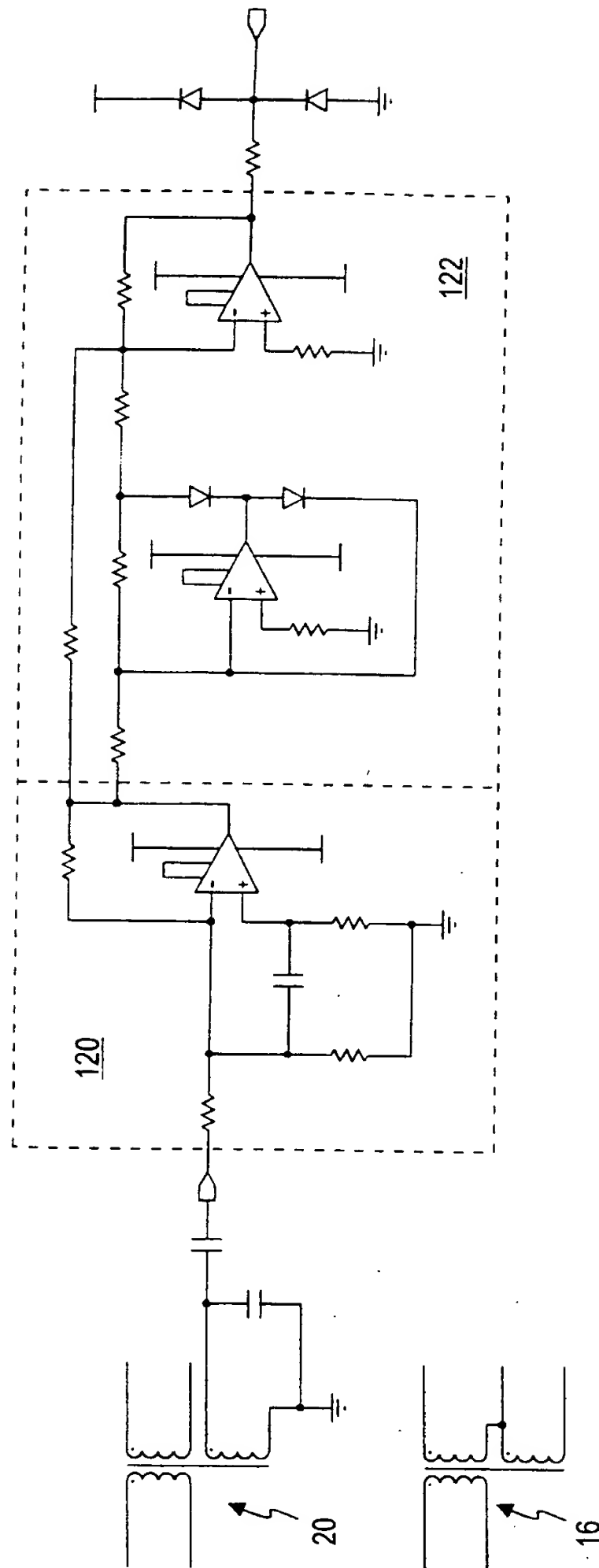


FIG. 6

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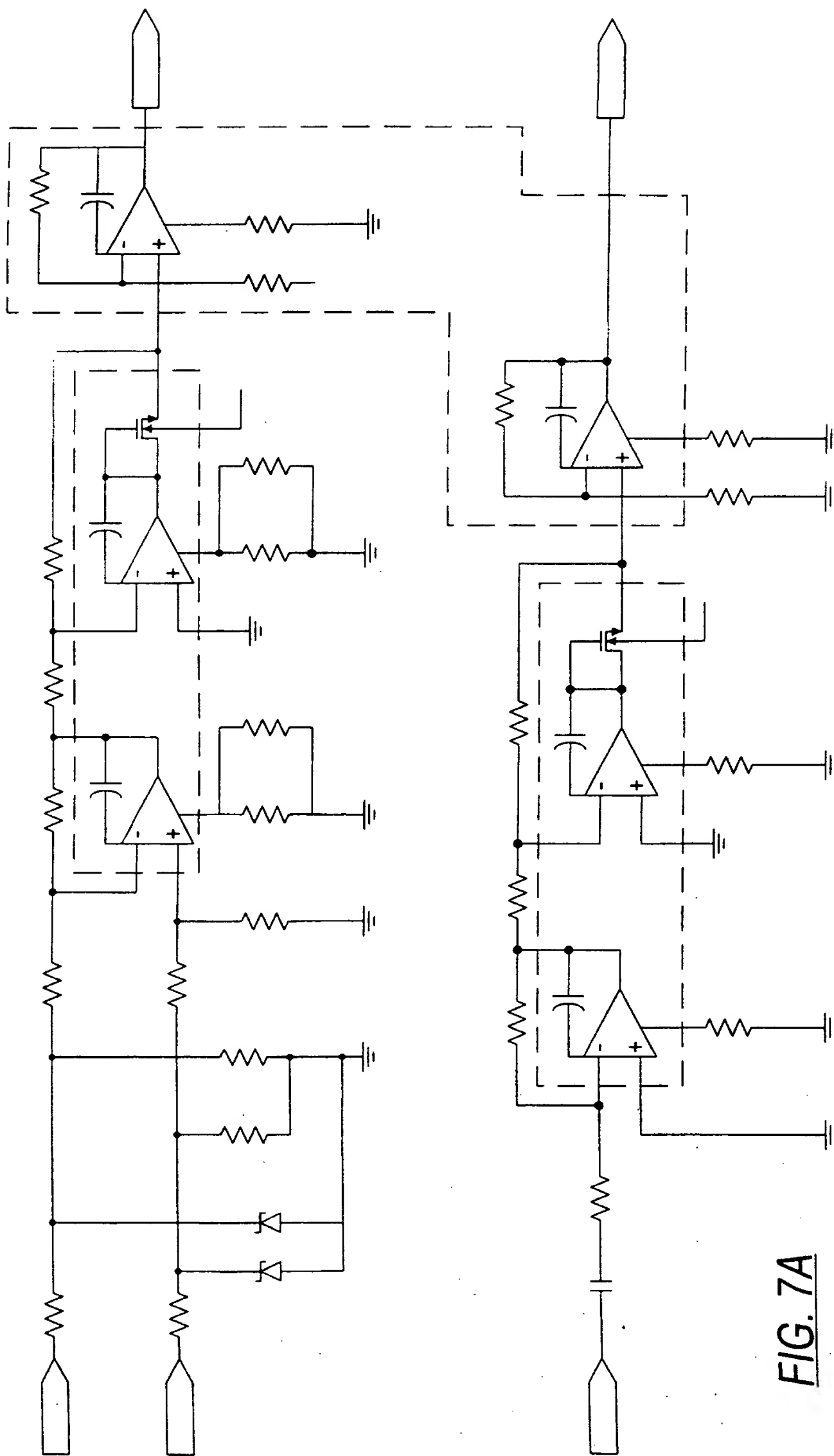
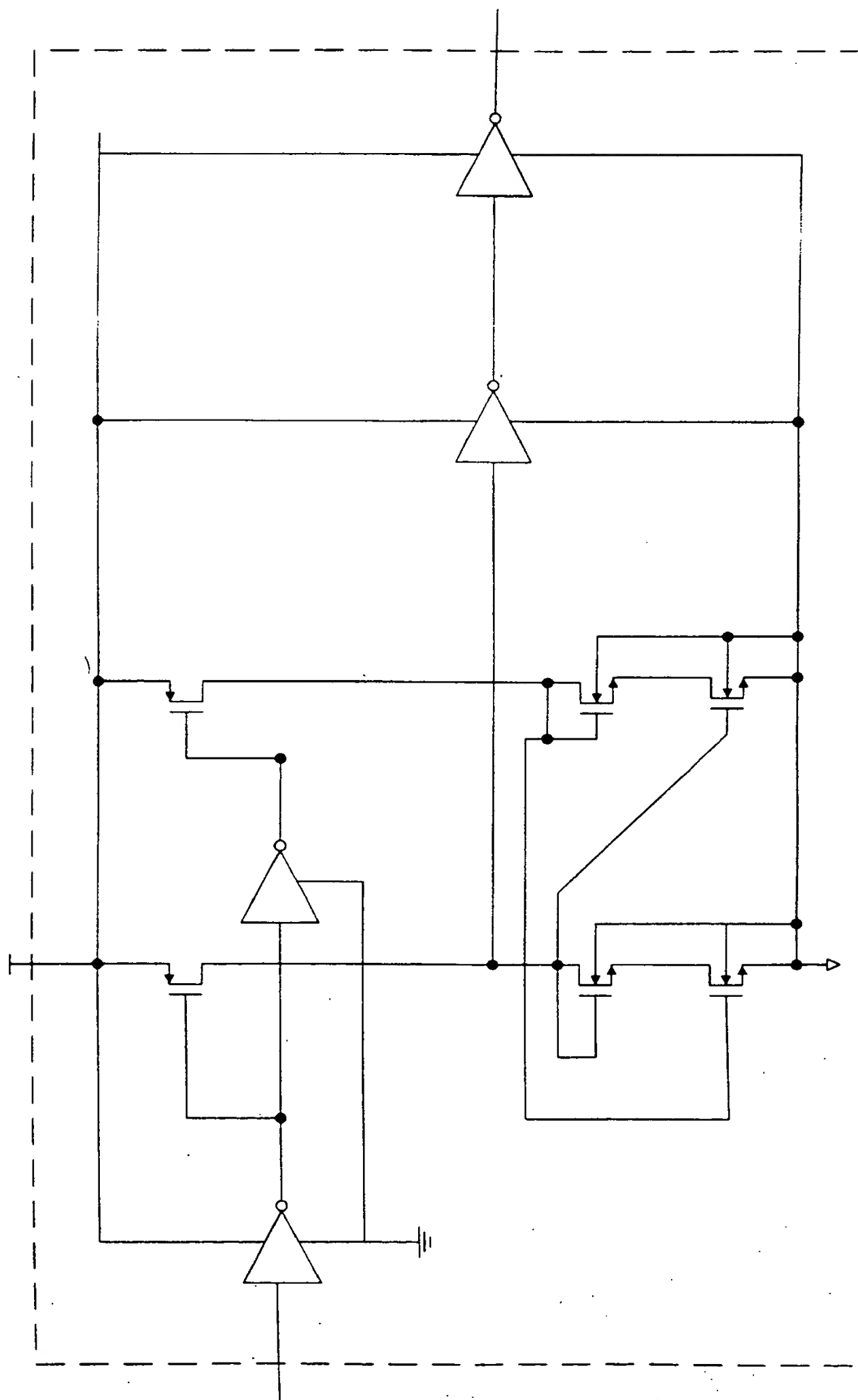


FIG. 7A

FIG. 7B



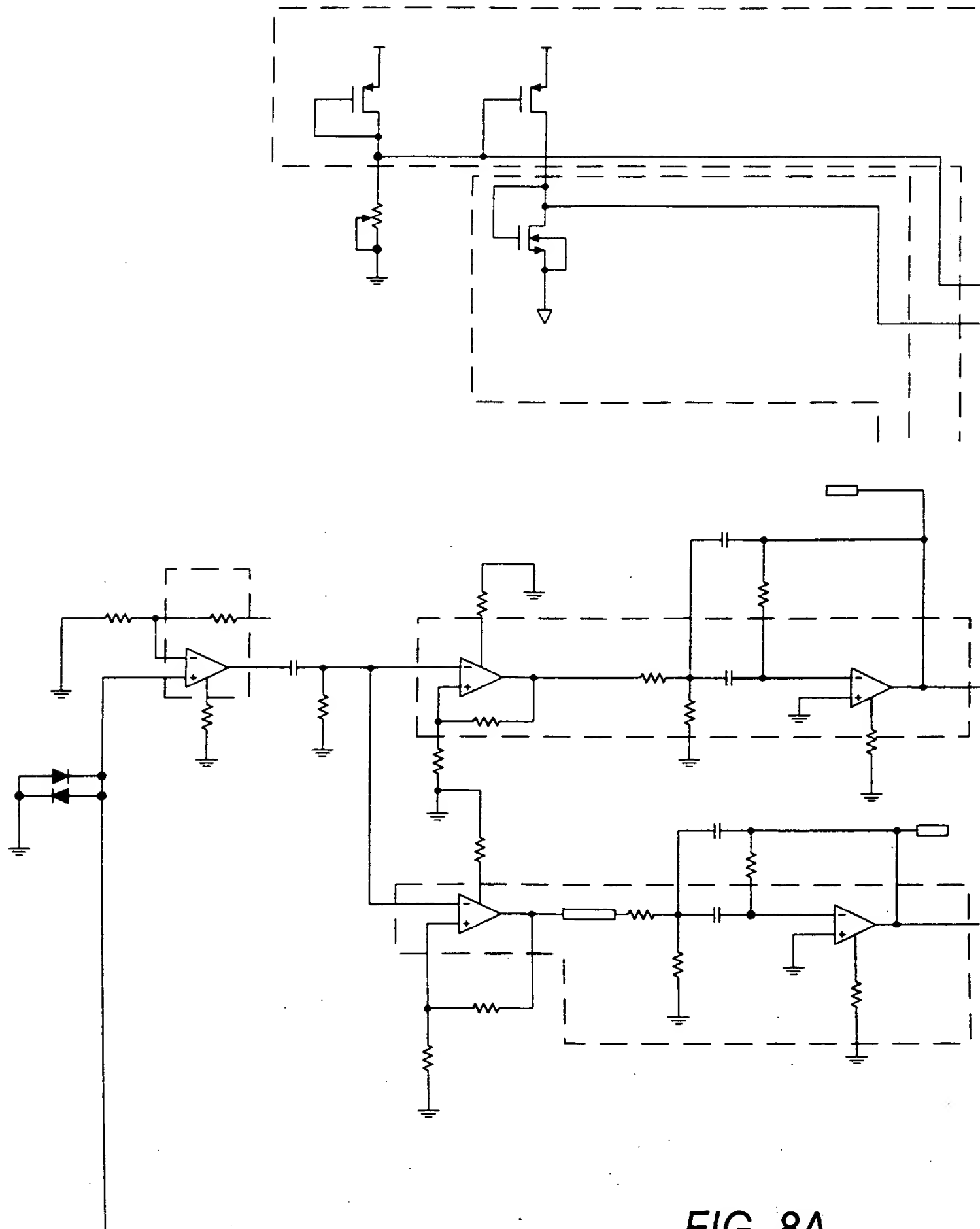
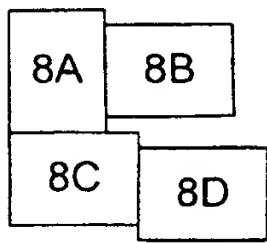
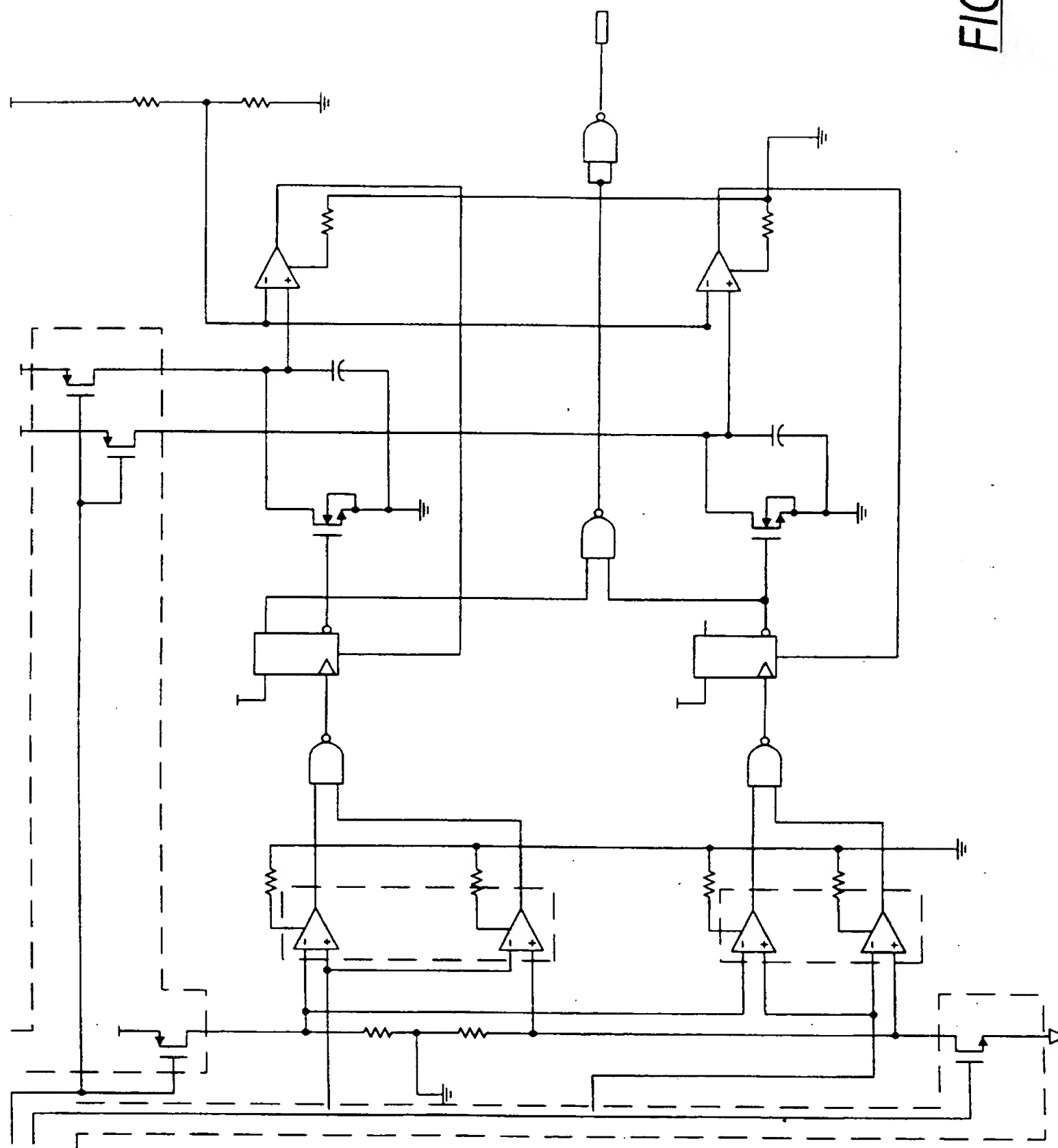


FIG. 8A

FIG. 8B



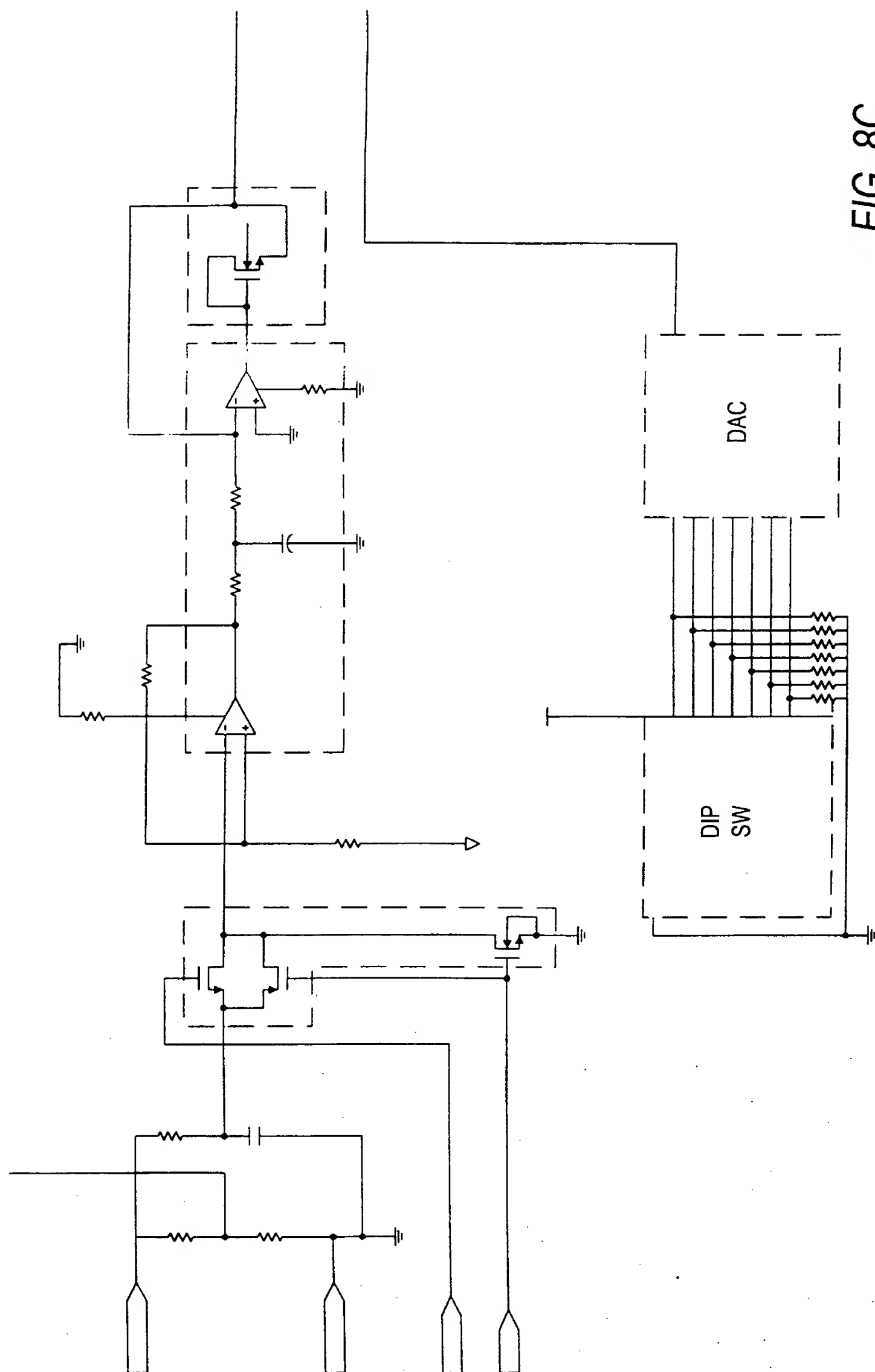
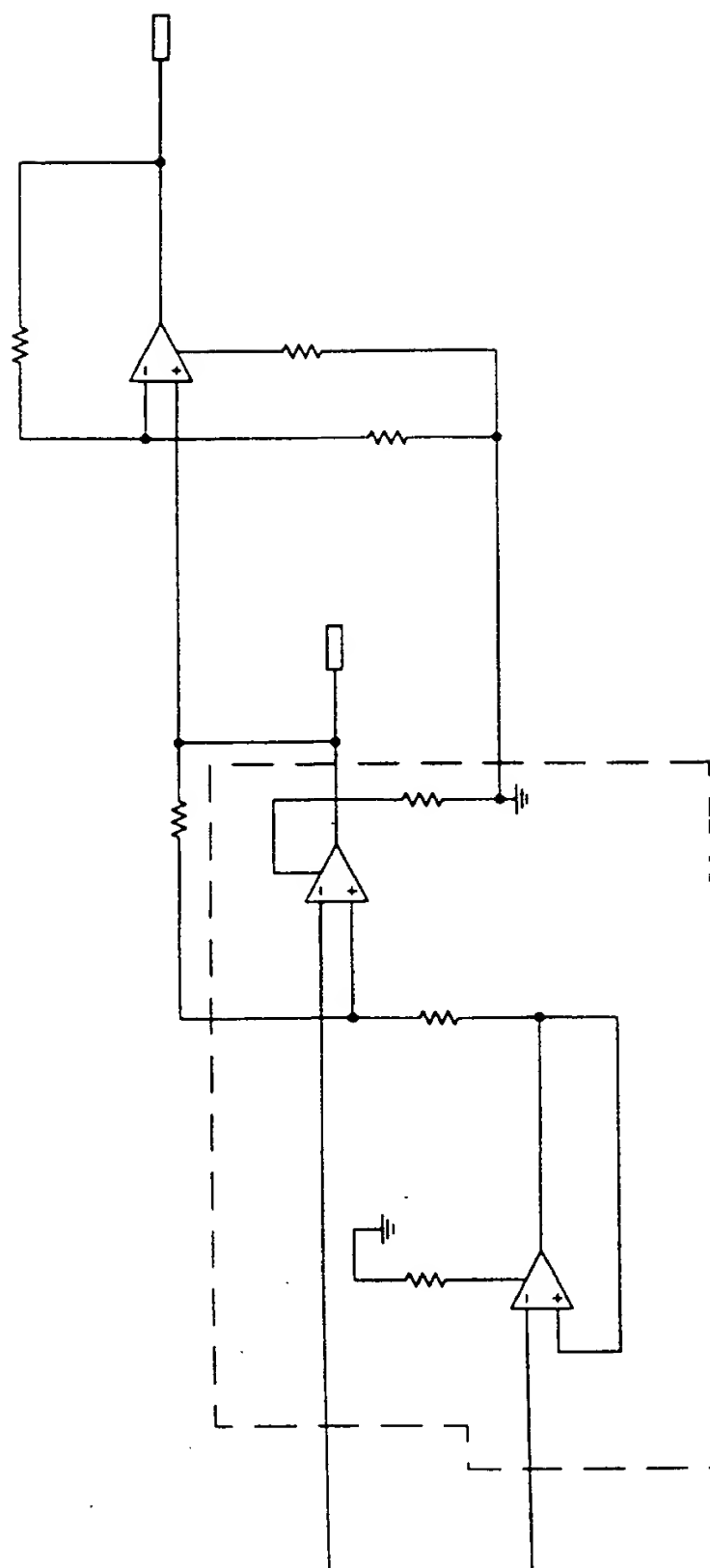


FIG. 8C

FIG. 8D



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INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/01801

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : H02H 3/00, 3/16, 3/26, 3/32, 9/08

US CL : 361/42-50

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 361/42-50

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

none

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

none

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X — Y	US 5,185,684 A (Beihoff et al.) 9 February 1993 (09.02.93), Figures 2, 7, 8, 12 & 17.	1-7, 11-27, 32, 35-52, 56-59 ----- 8-10, 28-31, 33, 34, 53-55
Y	US 5,459,630 A (MacKenzie et al.) 17 October 1995 (17.10.95) Figures 1, 3 & 4, col. 7, line 34 through col. 8, line 54.	5, 12, 16-25, 32, 35-52, 56-59

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search

12 APRIL 1999

Date of mailing of the international search report

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